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Hunting of Synchronous Machines

Electrical Engineering

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HUNTING OF SYNCHRONOUS MACHINES

BY

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THESIS

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HUNTING OF SYNCHRONOUS MACHINES.

I. Introdution.

With the extensive use of synchronous machines, the importance of thoroughly investigating the influence of electrical constants such as resistance and reactance, on hunting is obvious and has been the prime motive in writing this thesis. The electrical constants are so closely related, however, with the natural periods of the machines and the systems from which the machines are operating that we have found it necessary to consider all three factors.

It would be very difficult to study this problem by merely investigating formulae as conditions vary greatly and each case is generally an entirely new problem, but by the method exemplified in the following pages, we believe a clear conception of the subject can be obtained.

The results were not all that could be desired, but this was due mainly to the fact that only small units were available for test work. However the method is just as applicable.

II. General Theory.

Hunting is a term used to designate the oscillations of the rotating parts of machines when they are accelerated or decelerated with respect to normal speed. It is essentially a mechanical phenomenon and produces pulsations in the current, voltage and power, due to the variations of angular velocity (due to irregularity of torque) or to the electrical operation of the machines; and if the oscillations exceed a certain amount the regulation of the machines becomes unstable and they fall out of step.

Hunting may be due to the steam engine or even turbine, but with the advance of governing devices this is not likely to be the case, at least if the apparatus is kept in good order. It is more likely to be due to an incorrect amount of dampening of the magnetic circuit or in general to the electrical constants of the circuit. This dampening is produced by embedding a grid of copper in the pole face of the field magnets, the copper causing magnetic friction as soon as the oscillations occur. Eddy currents are induced in the copper due to the shifting armature magnetism which is produced by the armature oscillating back and forth across its normal position; and these currents react on the field and oppose the shifting thus dampening the oscillations. If the alternations of the supply are irregular the dampening devices tend to cause the motor to follow the irregularities, but they prevent an increase in the momentary phase displacement of the armature, thus having a steadying effect on the whole system. Hunting may also be due to the belt tension or in case the machines are on the same counter-shafting difficulties may be encountered due to very slight differences in diameters of pulleys.

Suppose that two alternators A and B are connected in parallel and that the armature of the machine A is behind that of the other; then the machine A receives a current which tends to pull it into phase and accelerate it so that when it reaches its correct phase position its speed is greater than that of B due to the inertia of the armature and A will run higher than synchronous speed and pass the synchronous point. Machine B will now be accelerated so that the machines will alternately lead and lag

setting up a vibration which is isochronous.

At any given instant the mean or normal position of a synchronous motor armature which is hunting is the position it would have at that instant if it were running at a constant angular velocity. When the motor hunts, the armature oscillates back and forth through its mean position. When in its mean position, the power intake and its belt load are equal, and a balanced torque acts on the armature. But when the armature gets ahead of its mean position its intake is lessened and the belt load exceeds the intake and an unbalanced torque acts on the armature. When the armature falls behind its mean position the intake exceeds the belt load, and an unbalanced accelerating torque acts on the armature. Now if the torque varies slowly there will be no free vibrations, but if the torque changes as the natural period of the machine then mechanical resonance, or hunting, occurs.

Dr. E.J.Berg has developed a formula for the natural period of machines which is as follows ;

$$N_1 = \frac{35000}{S} \sqrt{\frac{P \times f \times (mi_1 + n)}{WR^2 \times (m_o + n_1)}} \qquad (1)$$

Where,

N_1 = natural period of alternator in complete beats per minute.

S = revolutions per minute of alternator.

P = output in kilowatts.

f = frequency of impressed voltage.

WR^2 = moment of inertia of rotating parts.

i = power component of the current per phase.

i_1 = wattless lagging current per phase.

m = $1.5\sqrt{2}$ x t, in three phase machines, where

t = number of turns per pole and phase of the armature.

m_o = m/2 in definite pole machines.

n = ampere-turns field excitation from saturation curve corresponding to voltage $e + ir + i_1x$

$n_1 = n \times \frac{ix_o - i_1r}{e + ir + i_1x}$

x = inductive reactance per phase in the armature as obtained from synchronous impedance test and armature reaction.

x_o = 1.5 x, in definite pole machines.

The natural period of an alternator as given by the above expression is that period at which it will oscillate when adjusting itself from one load to another. The formula was developed on the assumption that the force at the periphery of the armature is similar to the force in the pendulum. It is further assumed, when using this formula for comparison of periods of two machines in parrallel, that one alternator is operating with another of larger capacity so that the larger one will be stable and not vary with changes in the smaller one.

The period of the hunting oscillations due to hunting of two synchronous motors operating in parallel, may be found from the equation :-

$$t^2 = \frac{2\pi^2 \cdot K (R^2 + X^2)}{p \cdot A \cdot B \cdot L}$$

Where,

t = period of hunting in beats per second.

K = moment of inertia of rotating structure in pound feet.

L = inductance of armature in henrys.

R = total resistance in circuit.

X = total reactance in circuit.

p = pairs of poles.

A = voltage of machine A.

B = voltage of machine B.

This formula was developed for two synchronous motors operating in parallel and having the same moments of inertia. In this work the machines were operated as alternators and the formula was changed so that R and X were the resistance and reactance between the machines instead of those of the entire circuit. In the case of the synchronous motors the motors constitute the load and this is inductive whereas in the case of the alternators the load was non-inductive.

The difficulties encountered in studying hunting when accurate data is to be obtained lies greatly in the preliminary work necessary, such as determining the proper amount of resistance to insert between the machines to be operated in parallel so as to obtain the maximum hunting and still to get suitable conditions for testing, obtaining the moment of inertia of the rotating structure, and obtaining the saturation curve of the machines as well as the resistance and reactance of the armature from the synchronous impedance test.

There are two general methods for obtaining the moment of inertia of an armature, i.e. by measurement and calculation, and by test. Obviously, owing to the fact that the armature of the

machine is a composite mass of irregular shape, it would be impossible to calculate the moment of inertia accurately from measurements, although it can be used as a rough check on the second method. In the test method, the armature is run at high speed and a known force applied ; the power is then suddenly thrown off and the rate of deceleration measured.

In this case the force applied was the stray power loss of the machine at normal speed and field excitation.

Let F = stray power loss in watts.

K = moment of inertia in gm. cm.

w = angular deceleration in radians per seconds.

t = time in seconds.

P = force applied, where $F = wP$ = work.

then, $P = K \frac{dw}{dt}$ = retarding couple due to applied force.

and, $F = Kw\frac{dw}{dt} 10^{-7}$ = watts lost in friction.

Solving for K we have,

$$K = \frac{F \times 10^{7}}{w \frac{dw}{dt}}$$

The value of F was determined as follows. The stray power loss in a direct current machine is the loss expended in turning the machine, when the field is normally excited and there is no current in the armature. The components of stray are,- bearing friction, brush friction, air friction, hysteresis, and eddy current losses. For a given adjustment of the field all of these losses remain constant for a constant speed.

The machine was run at normal speed as a d.c. motor with-

out load. Hence all of the input of the machine is used up as losses. The input was measured by reading E_o and I_o

where E_o = terminal voltage.

I_o = line current.

Let I_f = field current.

I_a = armature current.

R_a = armature resistance.

Since Input = Output + Losses

and since in this test the Output is zero then the Input is equal to the Losses.

Or $E_o I_o = I_a^2 R_a + E_o I_f + F$

where F = stray power loss. (the brush I^2R loss is neglected as it is very small)

Solving the above equation for F we have

$$F = E_o I_o - I_a^2 R_a - E_o I_f$$

In finding the moment of inertia of the machines the stray power loss as found was assumed to be constant while actually there was a change of speed. Since, however, the machine was speeded up to a point above normal and the time taken when it had reached a point the same r.p.m. below normal, so that the average speed was normal speed, it can be assumed that there was no change in the average value of the stray power loss.

Owing to the fact that the moment of inertia of the machine used was small there was a large deceleration in a short time making it hard to measure the rate of deceleration accurately. It was attempted to remedy this by replacing the light flywheel with a heavy one, but one could not be found of true enough fit

to enable it to be run at normal speed. The intervals of time were very accurately determined by the use of a stop watch.

The test method was checked by a calculation of the mo - ment of inertia from the dimensions of the machine.

The resistance and reactance of the armature were accurately determined by Messrs. Mench and Lagerstrom and found to be .08 and 1.12 ohms respectively.

III. Test Methods.

The machines tested were General Electric Rotaries, rated at 7.5 K.W., 4 pole, 68 amperes, 110 - 160 volts, 1200 - 1800 r.p.m. The armature winding is 4 circuit consisting of 96 coils, 3 turns, 576 conductors (144 in series per circuit).

At the beginning of the tests no attempt was made to ob - tain accurate data, the object being merely to obtain hunting so as to learn its mechanical nature. The alternators were separately driven by motors and were operated in parallel, a lamp bank being inserted between the machines for a variable resistance. Hunting was readily obtained but not of such a nature as to afford good operation due to the excessive resistance in the circuit. With the machines loaded the belt tension was varied, causing hunting, but as the tension was not an easy thing to calculate this method was not used further. It shows however that in some cases this may be a source of trouble. The field excitation of one of the driving motors was then varied and another source of hunting found. This method was impracticable as the change in the motor field could not be determined accurately. Furthermore the armature current in the alternator became excessive. One of the alternators was then operated in parallel with the university power plant and here

again hunting took place, even more readily than before due to the large resistance and partly to the variation of voltage of the power plant. During all these tests lamps were used as the resistance between the machines when it was decided that the resistance was altogether too high and iron wire was substituted.

The iron wire used was of a small diameter and was inserted in a pail of cold water to keep down the heating. The resistance drop was measured by means of a low reading alternating current voltmeter with the normal load current flowing, and the resistance obtained from Ohm's law. The alternators were operated in parallel as before and readings taken of power output of the alternators, power consumed in the load, voltages of both machines, and currents flowing in the alternators and the load. The data is shown in table 8. The load was varied from a minimum to the largest current that the machines would stand for various values of resistances.

A considerable time was spent in attempting to remedy hunting by means of a reactance coil, but it was finally decided to restrict the tests to causes rather than remedies. In these tests the O.D. Transformer was used but did not allow a sufficient range. The only reactance coil available was also tried, but the large ohmic resistance prohibited its use altho the range of reactance was quite satisfactory. If it is desired to obtain the effect of reactance it is suggested that a large number of transformers be connected in parallel to obtain sufficient reactance and a low resistance.

The power plant was then operated in parallel with the alternator again and readings taken as shown in table 1. The load

in this case was kept constant and the resistance varied. From the readings in the table, where the voltage, load and excitation were kept constant, it is evident that with the least resistance the machines were the most unstable.

The two alternators were operated in parallel again and readings checked with three values of resistance between the machines as shown in table 3.

The last test was taken with the alternator in parallel with the 100 K.W. General Electric Turbo-Alternator, so as to obtain better results by means of the formula given on page 3, which was originally for one machine operating with another of larger capacity. The two G.E. alternators were run up to speed by means of direct current motors. They were then synchronized and run in parallel with the turbo-alternator after which one of the direct current motors switches was opened. Readings were taken as before of power, voltage, and current. Oscillograph records are found on plates 3, 4, and 5.

The oscillograms show the phenomenon of hunting beautifully, but were not taken over a sufficient range to permit a comparison of succeeding cycles. Undoubtedly the cycles would not be repeated. The beats as read on the instrument are not strictly correct as the meters are not sensitive to the lesser variations due to the higher harmonics.

The natural period as calculated from Dr. Berg's formula is shown below as a sample calculation. All the other periods were obtained in the same manner. The data for this calculation is shown in table 1, reading 3. (Resistance between machines is .29 ohms.)

For alternator A.

$$N_1 = \frac{35000}{S} \sqrt{\frac{P \times f \times (mi_1 - n)}{WR \times (m_o - n_1)}}$$

S = 1800 r.p.m.

f = 60 cycles.

$P = \frac{4.1 - 4.9}{2} = 4.6$ K.W.

WR^2 = moment of inertia = 9.02 lb. ft.

m = 1.5 x 1.41 x t = 1.5 x 1.41 x 24 = 50.9 for 3 phase.

m = t = 24 for single phase.

$m_o = \frac{m}{2} = 12.$

Resistance of load = $\frac{E_B}{I_L} = \frac{94}{71} = 1.325$ ohms.

Resistance of armature = .08 ohms.

Resistance between machines = .29 ohms.

Total resistance = 1.695 ohms.

$\tan \theta = \frac{1.12}{1.695} = .662.$

$\theta = 33.5^\circ$

$\sin 33.5^\circ = .55.$

$\cos 33.5^\circ = .835.$

I_L = current in load.

I = total current = 45 amperes.

i = energy component. = I cosθ = 45 x .835 = 37.6 amperes.

i_1 = wattless component = I sin θ = 45 x .55 = 24.8 amperes.

mi_1 = 24 x 24.8 = 595. amp. turns.

$m_o i$ = 12 x 37.6 = 450. amp. turns.

E = 106. volts.

ir = 37.6 x .08 = .3 volts.

$i_1 x$ = 24.8 x 1.12 = 27.8 volts.

ix_o = 37.6 x 1.68 = 63.2 volts.

$i_1 r$ = 24.8 x .08 = 2.0 volts.

$ix_o - i_1 r$ = 63.2 - 2.0 = 61.2 volts.

$$e + ir + i_1 x = \sqrt{E^2 - (ix_o - i_1 r)^2}$$

$$= \sqrt{(106)(106) - (61.2)(61.2)}$$

$$= 86.7 \text{ volts.}$$

n is found from the saturation curve (Plate 1) corresponding to $e + ir + i_1 x$ (86.7 volts) and is equal to 1620. ampere turns.

$$n_1 = \frac{ix_o - i_1 r}{e + ir + i_1 x} \times n = \frac{61.2}{86.7} \times 1620 = 1142.$$

$mi_1 + n$ = 595. + 1620. = 2215.

$m_o i + n_1$ = 450. + 1142. = 1592.

Finally on substitution

$$N_1 = \frac{35000.}{1800.} \sqrt{\frac{4.6 \times 60. \times 2215.}{9.02 \times 1592.}}$$

= 127.0 beats per minute.

IV. Conclusions.

In the preceding calculations we have found the natural periods of the two machines used for various loads and with varying values of resistance between the machines. The hunting of the machines is determined directly from the values of the natural periods, being a maximum when the periods are equal so that the beats become cumulative. Dr. Berg has given us a formula for plotting these values to show the actual conditions.

$$y = e^{-\theta_1 t} \sin 2\pi f_1 t + e^{-\theta_2 t} \sin 2\pi f_2 t \qquad (1)$$

where, y = the ordinate of the curve for any value of time t.

t_1 and t_2 are the periods in terms of t of the respective machines.

θ = the phase angle.

It would be very interesting and instructive to plot the above curve from two values of f_1 and f_2 taken from the data but this would be a very long solution, and the study of the theory of hunting can be just as well understood by assuming the curves to be sine waves and to solve for

$$y = \sin 2\pi f_1 t + \sin 2\pi f_2 t \qquad (2)$$

the difference being that this curve will leave out of consideration the harmonics in the system.

This curve has been plotted on Plate 2. It is seen that this curve is very irregular, no two consecutive cycles being similar.

It is principally for this reason that the formula developed by Franklin and Esty of $t^2 = \frac{2\pi^2 K (R^2 + X^2)}{p \times A \times B \times L}$ for two

similar synchronous motors was considered incorrect, because from the curve we can see that there is no definite period of hunting, which period it was supposed to represent. The value of this formula is not very evident. It is generally understood that resonance takes place when the two machines have the same or nearly the same periods. If they have exactly the same periods they fall out of step directly due to cumulative hunting, whereas if they have nearly the same periods they will hunt most where the waves are in phase and then less for a number of cycles until the waves again become coincident, as can be shown by oscillograph records or by the resultant wave on Plate 2. The formula as shown may mean that the maximum hunting will occur when each machine has a period as given by the value of t. This would not necessarily infer that hunting would not occur at any other period, but when it was attempted to check our results by this method the values obtained differed widely from those obtained by other methods. However, if the formula holds for synchronous motors as stated the assumption is reasonable that it should hold true for our case which was exactly similar except that the machines were operated as alternators.

If oscillograph records had been taken covering several periods they would have shown conclusively that there was no definite period. These oscillograms would have been similar to the calculated curves except that the higher harmonics would have appeared to make the edges jagged instead of smooth. This is shown by the records that were taken. (See Plates 3 and 4.)

In the test as carried out, the total field excitation was kept constant, and since the armature reactions increased for

increased loads there was in this case a drop in the terminal voltage. There was not any material change in the value of the natural periods with the loads, showing that for constant field excitation the hunting is entirely independant of the load. If, however, the terminal voltage is kept constant for increased loads, this would have required an increase in field ampere turns which would mean a stiffer field and hence a higher natural period. It is for this reason that it has been found in actual practice that a machine will hunt at half or three-quarters load, while if it is quickly made to take on full-load it will run in perfect stability.

The value of resistance between the machines was varied so that for full loads the per cent resistance of terminal voltage varied from sixty to two per cent. It was found that for values above thirty per cent there was almost no stability between the machines, the reason being that with the machines hunting the high resistance caused the current to be more nearly in phase with the resultant voltage of the synchronous motor and generator, while it was drawn out of phase with the motor voltage so as to leave less energy component to pull the two into step again. The maximum hunting seemed to occur when the per cent resistance was about five per cent.

It would be interesting to study the effect of reactance upon hunting determining if possible the per cent reactance necessary to overcome a certain per cent resistance in the line. This would be of commercial value in determining the size of coils to place between the machines to prevent such trouble.

By far the most important factor to be considered in this problem is the resistance between the machines, as has been shown

by the data obtained and in practical work the ohmic resistance should be kept as low as possible. The size of the machines also has a great influence upon the period since the moment of inertia depends entirely upon the size and shape. Also the frequency plays an important part so that the critical frequency could be determined or that frequency at which cumulative hunting would occur.

From the above discussion it will be seen that hunting is dependant more or less upon nearly every constant of the machine and line, making its study indefinite and never entirely satisfactory.

V. DATA AND RESULTS.

TABLE 1.

Two G.E. Alternators in Parallel with Variable Resistance Between Machines. (Data and Results for Machine A)

Reading	W_A	W_L	I_A	I_L	E_A	Resistance Inserted.	Natural Period.
1.	1.5--2.5	1.7	15.	19.	111.	.416	132.0
2.	3.1--3.4	4.1	31.--34.	50.	106.	"	129.0
3.	3.6--3.9	5.6	36.--42.	70.5	104.5	"	118.0
4.	4.1--4.2	5.8	42.--49.	78.	104.	"	127.0
1.	2.8--3.1	2.6	26. --29.	32.7	112.	.290	119.0
2.	3.9--4.2	5.2	39.--41.	63.3	106.	"	127.0
3.	4.1--4.9	5.8	40.--5.0	71.	106.	"	127.0
4.	3.9--4.2	6.0	38.--46.	74.	103.	"	125.0
1.	3.1--3.8	4.	29.--33.	45.	106.	.0836	123.0
2.	3.2--3.9	5.2	45.--57.	62.	101.	"	100.0
3.	3.9--4.2	6.3	43.--50.	72.	99.	"	118.0
4.	3.9--4.9	6.4	42.--55.	77.2	98.	"	128.0
1.	3.7--5.3	5.7	44.--46.	61.	104.0	.0217	118.0
2.	5.8--6.4	7.0	60.--66.	80.7	97.0	"	139.0
1.	2.5--4.5	4.8	35.--42.	55.	101.	.0285	114.0
2.	3.5--6.5	6.8	53.--63.	80.	96.0	"	127.0

V. DATA AND RESULTS.

Table 2.

Two G.E. Alternators in Parallel with Variable Resistance Between the Machines. (Data and results for Machine B)

Reading	W_B	I_B	E_B	Resistance Inserted.	Natural Period.
1.	-.2	10	104	.416	.120
2.	2--2.2	24.5	96.5	"	107
3.	2.9--3.2	39	91	"	110
4.	3--3.1	41--42	89	"	97
1.	.4--.6	10	104	.290	103
2.	2.2--2.4	27--28	96	"	109
3.	2.6--2.8	34--36	94	"	102
4.	2.8--3.2	38--40	91.5	"	107
1.	1.6--1.8	20	102	.0836	107
2.	1.8--2.2	36--38	98	"	89
3.	2.9--3.2	38--39	96	"	106
4.	2.9--3.4	43--47	95	"	115
1.	1.5--1.4	20	106	.0217	145
2.	1.9--2	23.5	96	"	115
1.	1.8--2.6	18	101	.0285	119
2.	2.6--2.3	27--28	96	"	120

V. DATA and RESULTS.

Table 3.

Two G.E. Alternators in Parallel with Variable Resistance Between the Machines.

Reading No.	W_A K.W.	W_B K.W.	W_L K.W.	I_A Amps.	I_B Amps.	I_L Amps.	E_A Volts.	E_B Volts.	Resist. Inserted Ohms.
1.	5.1 to 5.2	1.to 1.2	6.	52.to 57.	13.to 15.	69.5	102.5	109.	.319
2.	4.1 to 4.2	1.7 to 1.9	5.8	43.to 47.	20.to 22.	64.	103.	105.	.121
3.	5.2to 5.4	1.8to 2.2	7.1	56. to 61.	21.to 23.	81.	99.	102.	.0666

V. DATA and RESULTS.

Table 4.
The G.E. Alternator and Turbo - Alternator in Parallel
With Variable Resistance Between the Machines.

Reading No:	W_A K.W.	W_B K.W.	W_L K.W.	I_A Amps.	I_B Amps.	I_L Amps.	E_A Volts.	E_B Volts.	Resist. Inserted Ohms.
1.	0. to 2.0	0. to .7	4.2 to 4.4	0. to 30.	0. to 13.	49.0	96.	98.	.066
2.	0. to 3.5	0. to 5.0	5.5 to 6.8	0. to 33.	13. to 19.	71.	95.	98.	.0334
3.	.6 to 1.8	.7 to 1.2	5.4 to 5.0	0. to 30.	15. to 30.	65.	95.	92. to 102.	.187
4.	.6 to 1.8	0. to 1.5	5.7 to 6.1	10 to 23.	12. to 16.	69.	90. to 97.	90. to 100.	.0916

V. DATA and RESULTS.

Table 5.

Alternator and Turbo - Alternator in Parallel. (Showing Calculations for the Natural Period for Alternator B.

Resistance	.066	.0334	.187	.096
K.W.	.35	.25	1.	.75
I	6.5	16.	20.	14.
i	5.8	12.4	16.8	11.3
i_1	3.0	10.	11.	8.3
E	98.	95.5	97.	95.
$ix_o - i_1x$	9.5	20.	27.3	18.3
$e + ir + i_1x$	97:4	93.4	93.	93.3
n	1980.	1840.	1830.	1840.
mi_1	140.	300.	400.	270.
n_1	200.	390.	540.	360.
m_oi	36.	120.	130.	100.
$mi_1 + n$	2120.	2140.	2230.	2110.
$m_oi + n_1$	236.	510.	670.	460.
N_1	89.0	91.	93.	93.

The average of the ammeter beats was 106.

V. DATA and RESULTS.

Table 6.

Two G.E. Alternators in Parallel. (Showing Calculations for the Natural Periods of the two Machines)

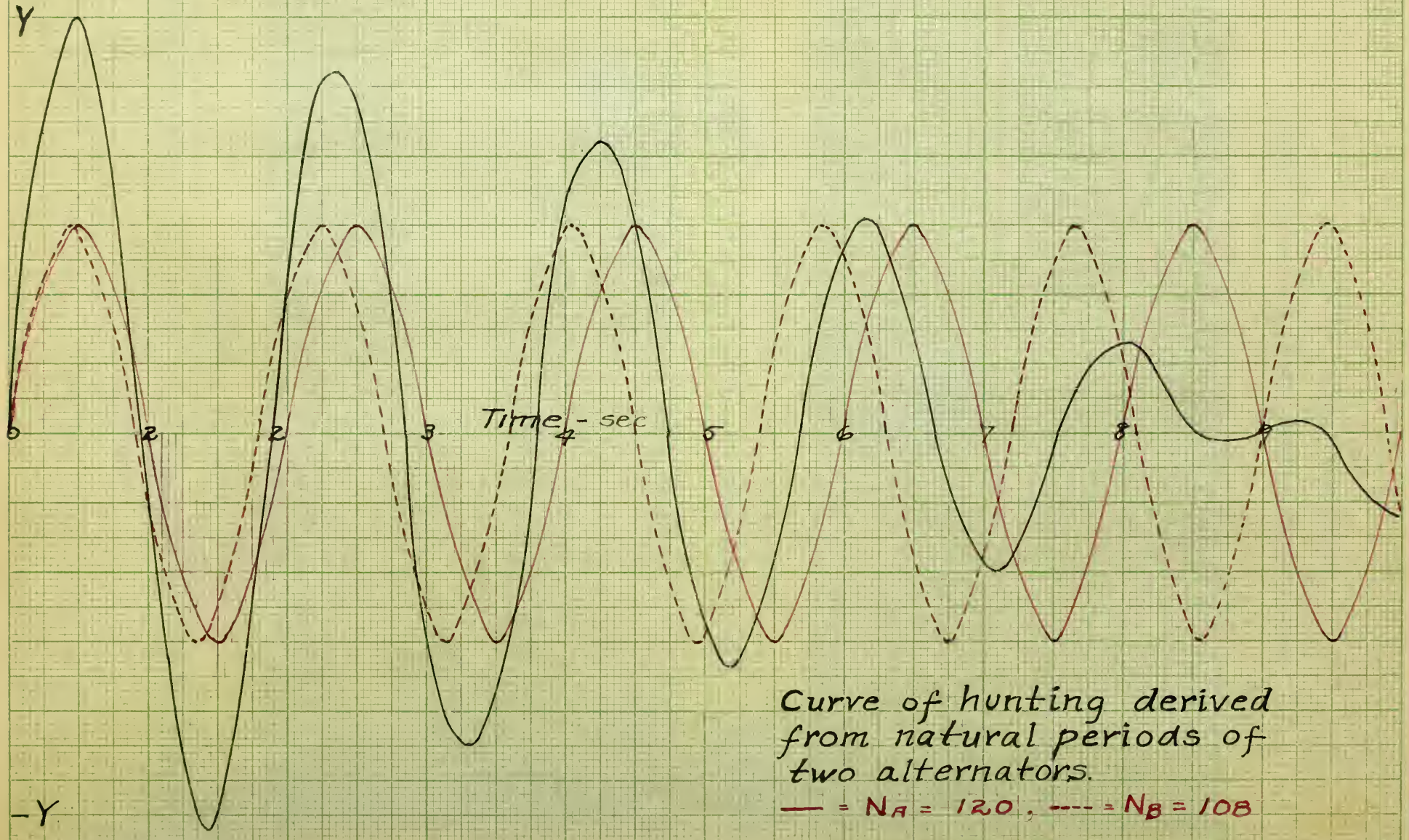
Resistance		.319	.121	.066		.319	.121	.066
I	For	54.	4.1	5.3	For	1.1	1.8	2.0
i	Alt.	46.7	38.3	45.3	Alt.	12.1	17.8	17.1
i_1		27.8	23.7	37.2		7.2	11.	14.
E	A.	102.5	103.	99.	B.	109.	105.	102.
$ix_o - i_1r$		76.3	62.4	73.		19.7	29.	27.6
$e + ir + i_1x$		68.5	81.8	66.8		107.2	100.8	98.
n		1080.	1470.	1040.		2400.	2100.	2000.
mi_1		670.	570.	890.		170.	265.	336.
n_1		1200.	1120.	1140.		440.	604.	563.
m_oi		560.	460.	545.		145.	214.	205.
$mi_1 + n$		1750.	2040.	1930.		2665.	2365.	2336.
$m_oi + n_1$		1760.	1690.	1685.		595.	818.	768.
N_1		114.	111.	122.		138.	114.	124.

E.M.F.

Plate I

Open Circuit
Saturation Curve
of
Rotary Converter # 28366

Plate II



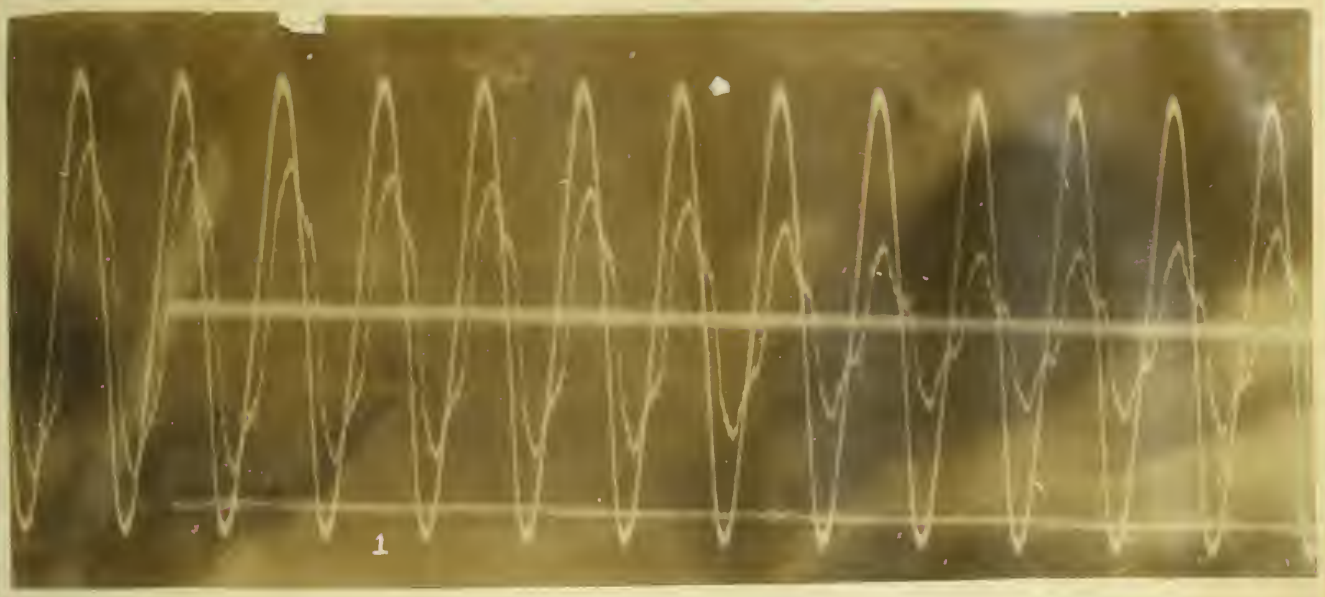
Curve of hunting derived from natural periods of two alternators.

—— = N_A = 120 , ---- = N_B = 108

VI. PLATES.

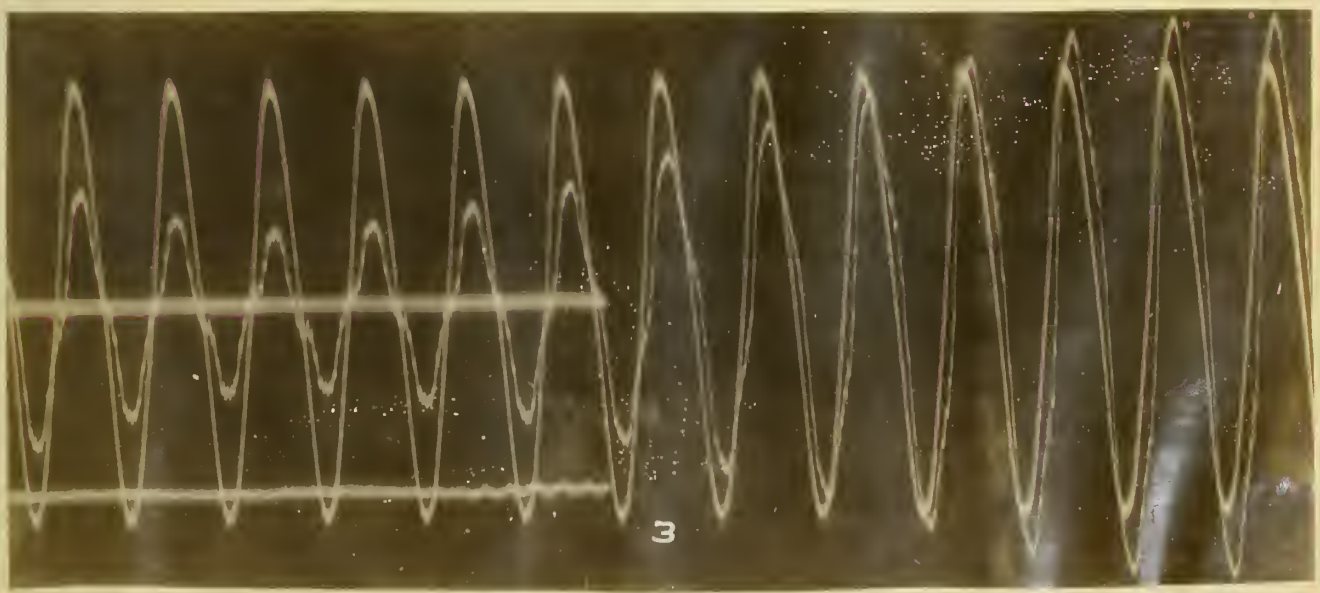
Plate 3.

Oscillograph Records Showing Hunting of the Two G.E. Alternators in Parallel Operation.



Resistance Between Machines .319 ohms.

Calibration = 30.5 Amperes.



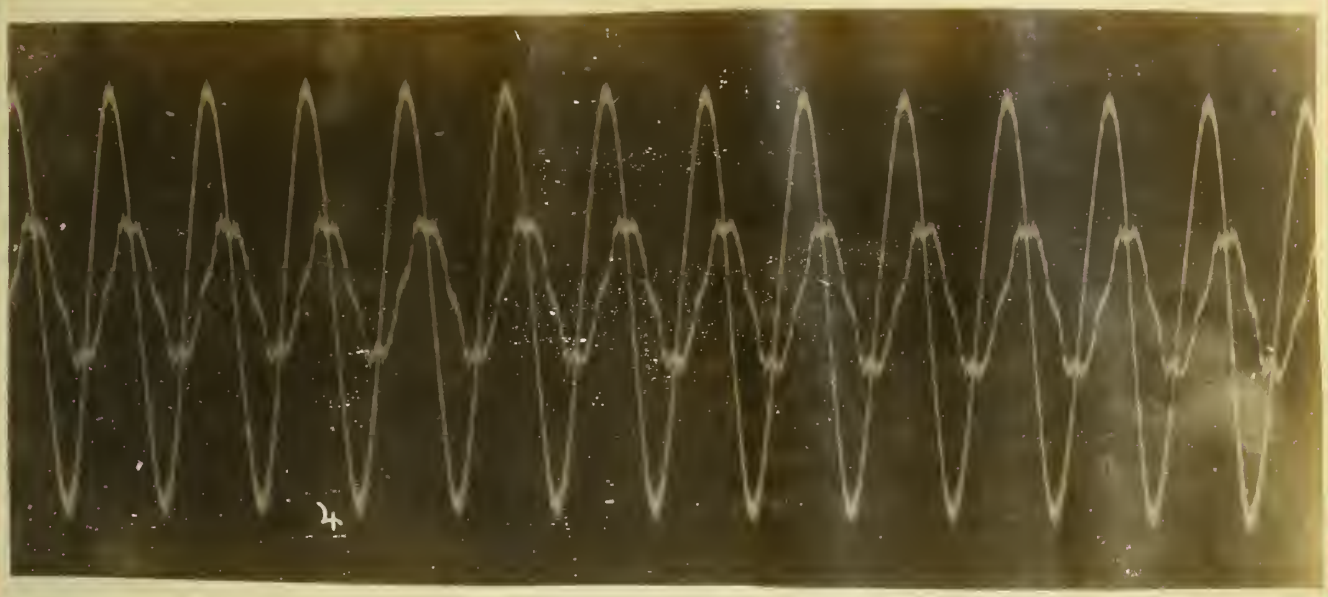
Resistance Between Machines .0666 ohms.

Calibration = 30.0 Amperes.

VI. PLATES.

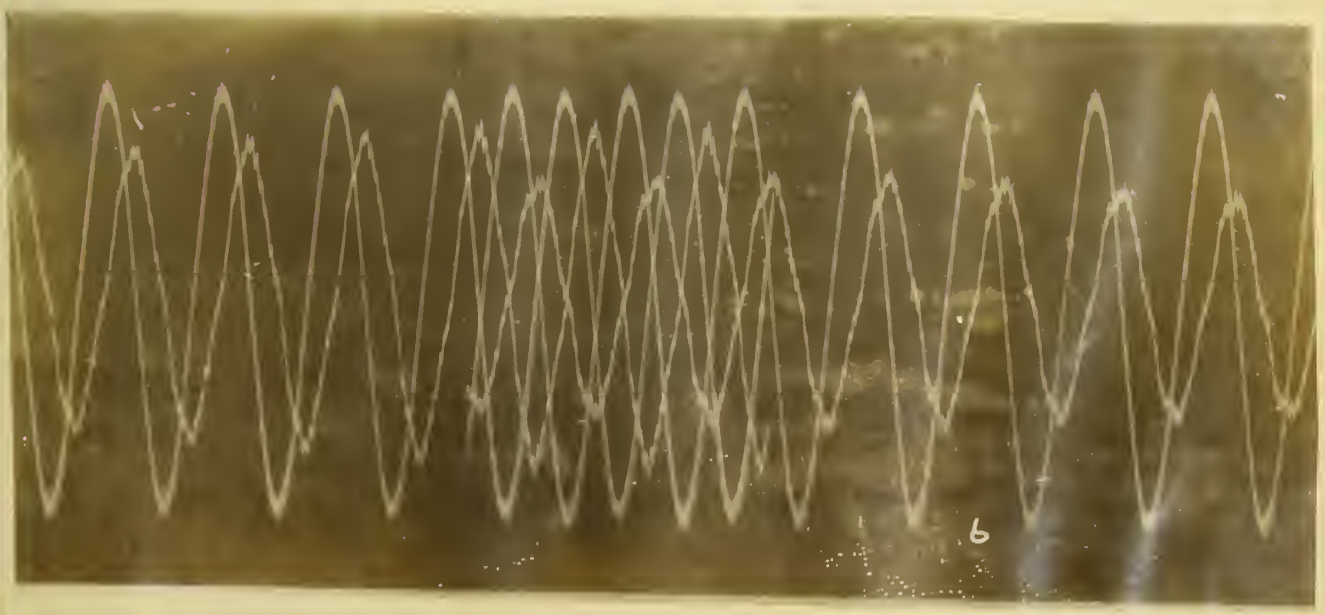
Plate 4.

Oscillograph Records Showing Hunting of Turbo - Alternator and Alternator in Parallel Operation.



Resistance Between Machines .066 ohms.

Calibration = 28.0 Amperes.



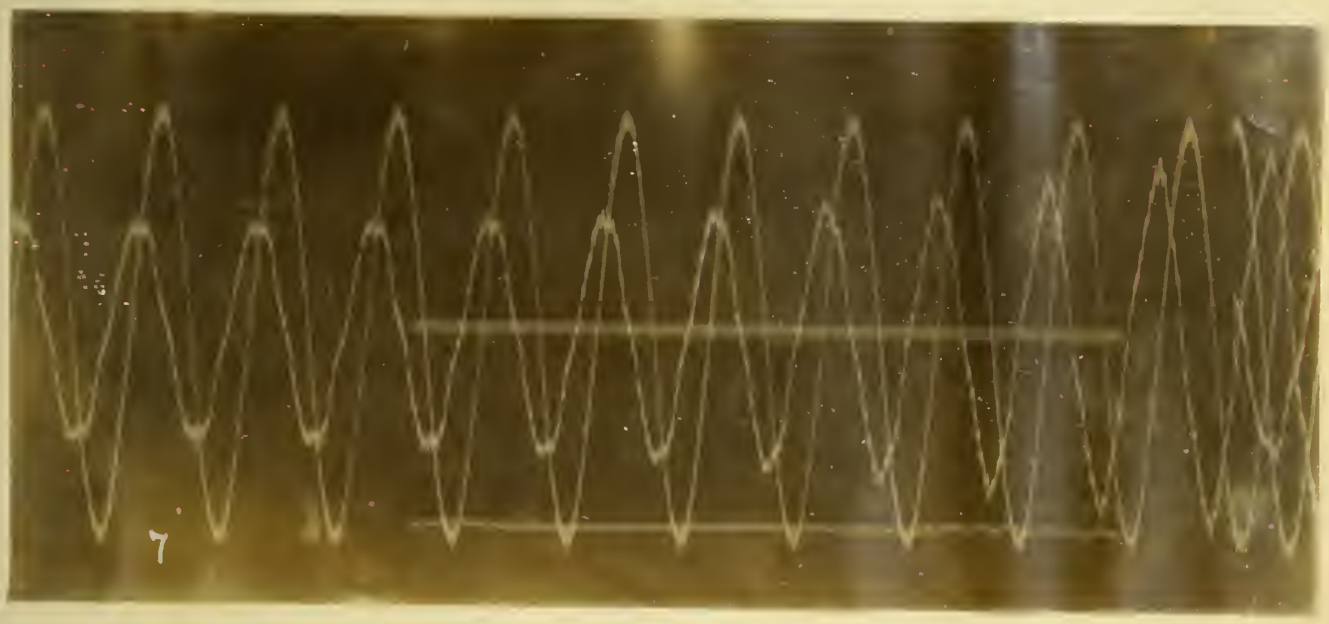
Resistance Between Machines .187 ohms.

Calibration = 32.0 Amperes.

VI. PLATES.

Plate 5.

Oscillograph Records Showing Hunting of the Turbo - Alternator and Alternator in Parallel Operation.



Resistance Between Machines .0961 ohms.

Calibration = 31.7 Amperes.

VII. SUPPLEMENTARY DATA.

TABLE 7.

G.E. Alternator and Power Plant In Parallel Using Lamp Banks As The Variable Resistance Between The Machines.

E_o	E_{pp}	I_o	I_{pp}	W
109.	111.	10.	3.	.15
111.	108.	10.	3.	.3
111.	107.	10.	5.	.5
110.	106.	10.	8.	1.0
103.---	90.--	0-----	10. ---	0-----
105.	118.	24.	25.	3.0
100.---	90.--	0-----	11.----	0-----
130.	118.	29.	29.	3.4
80.----	70.--	0-----	20.----	0-----
155.	135.	29.	30.	5.0
70.---	70.---	0-----	15----	0----
110.	110.	23.	28.	2.5
72.----	70.--	0----	15.--	0---
115.	100	23.	31.	3.5
80.---	65.--	0-----	20.--	0--
112.	100.	24.	33.	4.8
85.---	0----	0----	22.--	0---
145.	120.	24.	35.	5.1
90.--	75.---	0---	35.--	0---
115.	90.	25.	38.	3.3
95.--	75.---	0---	35.--	2.--
105.	85.	25.	41.	3.6
0---	0---	0---42.	30.--	0--
120.	110.		47.	5.0
0---	0----	0---42.	35.--	0--
145.	116.		50.	3.0
80.--	0----	0---42.	40.--	2----
110.	115.		53.	4.
90.--	70.---	15---30.	48.--	3.--
110.	80.		56.	4.0

VII. SUPPLEMENTARY DATA.

TABLE 8.

G.E. Alternator and Power Plant In Parallel Using Iron Wire As The Variable Resistance Between the Machines.

Reading	E_o	E_{pp}	I_o	I_{pp}	K.W.	Field Current	Resistance Inserted
	108.		31.--	40.--			
1.		108.	33.	62.	0--5.0	1.95	.033 ohms
			32.--	38.--			
2.	110.	110.	35.	55.	"	1.95	.016 "
			29.--	44.--			
3.	110.	110.	30.	68.	"	1.95	.041 "
	30.--		45.--	40.--			
4.	90.	105.	48.	100.	"	1.8	.416 "
	34.--		43.--	39.--			
5.	36.	109.	45.	60.	"	1.65	.415 "

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